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HUMAN INFORMATION PROCESSING

AND

INTERACTIVE COMPUTING

Human Information Processing
and
Interactive Computing

Albert N. Badre
Atlanta, Georgia

1. Introduction

Man-machine interface studies have been conducted mainly in an effort to improve machine usability. In the early studies, the human was viewed as a component of the interactive system similar to that of the machine (Chapanis, 1965). Machines were used to perform some fixed functions in a man-machine system. The bulk of the research on man-machine interface was concerned with the motor skill aspects of man's interaction with and performance on the machine. This approach was acceptable when machines were simple and non-adaptive. But with the advent of the modern electronic and adaptive logic computers, a host of new possibilities for human-machine interaction and a new set of problems for researchers in the area of man-machine interface are emerging (Badre and Ting, 1974; Ting and Badre, 1976; Glorioso, 1975).

It is becoming increasingly necessary to explore and identify the human information processing factors, constraints, and variables that would bear on the design of user-compatible systems. User interface concepts are being formulated and considered in relation to various problems such as representing, displaying, storing, accessing, manipulating, and generally using information for human-computer interactive environments.

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The modern computer-based interactive systems are significantly different from the traditional machines in that they are designed to respond to the human at both the motor skill and information processing levels (Badre and Slamecka, 1976). Computer based devices have the built-in capability to dynamically change their functions in order to adapt to the information processing needs of the man component. They act as adaptive logic units in a manner similar to that of intelligent organisms for performing a service role in a man-machine environment (Davies and Barber, 1973). Furthermore, the easy availability of on-line access on graphic and relatively intelligent terminals enhances the adaptive and information processing capabilities of the computer. Hence, researchers in the area of man-machine interface have recently become interested in the possibility of using computers to augment the human cognitive process. Many scientists are now engaged in systematically studying the use of computer-based devices as effective decision-making, problem-solving, and information processing aids to the human in real world tasks such as training, medical diagnosis, tactical decision-making, management problem-solving, and intelligence gathering and analysis (Davis, Buchanan, and Shortliffe, 1977; Martin and Badre, 1977; Martin, 1973).

2. Objective of Study

The aim of this study is to specify some of the more pertinent variables and constraints that need to be considered in designing user-compatible interactive systems. This in turn would lead to

a review and consideration of some of the various empirical studies that have examined various human information processing factors that bear on the effectiveness of interactive computing. Accordingly a three-fold strategy is followed in this report:

(a) A general discussion of interactive computer systems where the concept of interactivity is delimited, and made sufficiently precise for the purposes of this report;

(b) A systematic specification of the various human information processing factors, variables, constraints, and functions that are likely to impact the design and effective use of interactive systems; the intent here is to delineate and describe some of the more basic human information processing variables such as representing, storing, and accessing information;

(c) A review and consideration of some of the studies that delineate selected empirical results regarding human information processing factors that impact user-compatible interactive environments.

3. Human-Computer Interaction: A Definition

In a broad sense of the word "interaction", interaction between humans and computers may be said to occur when the effective sequencing of information flow and feedback to and from both the

human and machine components takes place. Even though by this definition, the batch mode is a special case of interaction that is differentiated from the on-line mode in the time it takes to elicit a response from the machine component, for the purposes of this study, the word interaction will be reserved for on-line modes and differentiated from remote modes of communication.

A more precise definition of man-machine interaction has been developed in earlier studies (Badre and Ting, 1974; Ting and Badre, 1976). The following is an exact definition as was stated in Ting and Badre (1976). It was conceptualized that at the most elementary level, interactive computer-based man-machine logic systems may be described in terms of a man, P, and a machine, M, that are linked by a rather close and direct channel of communication. The P and M depend on each other in the changing of states for moving toward a specified objective. The state of the man-machine logic system changes along with each interactive action. Usually, P makes an initial move to which the system responds. This response stimulates P to take another action which in turn causes M to react. This interaction goes on continuously until one of three things happens:

- (a) the objective is satisfied by P;
- (b) the P reaches a threshold point of "fatigue" beyond which he can no longer act;
- (c) the machine breaks down because of malfunction.

It is desired that the man-machine interaction be terminated only by condition (a). The assumption made here is that in order

to minimize the occurrence of condition (b) and raise the threshold point of P's willingness to use the system, it is necessary that: (1) M be flexible in its capacity to serve P and, (2) P's subjective judgment be satisfactory with respect to the operational functioning of M. The occurrence of condition (c) may be reduced as a function of M's operational reliability.

More precisely, the type of P-M interaction that is defined at the most elementary level of interaction, may be identified in terms of four necessary conditions. The P-M interaction must be: (1) purposive; (2) close-linked; (3) man-controlled, machine-adaptive; and, (4) one-to-one related.

(1) The P-M logic system must be a purposive one. This condition requires that the purpose be predefined by the system's designer, and that P uses the system for this predefined purpose.

(2) Man and machine are linked in a direct and close loop. This requires that: (a) physical contact be made between P and M by an on-line peripheral device; (b) communication be achieved through this on-line device by means of a well-defined artificial language; (c) two-way communication be achieved by a quick response from the machine expressed through the output peripheral device in a form which is easily understood by P. Overt actions are necessary in operating these devices both by P and by M for communications.

Actually, in this case, the man-machine interaction may be better described as man and system interaction. The

terminal devices which are directly controlled by the human component are only the communication channels for the exchange of messages. The actual machine component is a total logic machine system directed by an intelligent computer.

(3) The interaction is a man-centered activity in that P is active and M is reactive. However, both P and M are adaptive. The man adapts to the machine in order to use it. The machine is adaptive in that it meets P's confidence requirements for facility and satisfaction of use.

(4) A one-to-one relationship between P and M must exist as a condition for interaction. This condition requires that in a P-M interaction, $P = 1$ and $M = 1$, over a given time limit. A machine may interact with a multiple number of users at one time, but nevertheless, each communicates with the machine independently and without interference. This situation is considered equivalent to several independent P-M interactions. The above described P-M interaction may be illustrated by a simple conceptual model presented in the diagram (see Figure 1).

The model indicates that P-M interaction may be viewed as a continuous two-way communication in a closed feedback loop between P and M. Through the interaction, the predetermined objectives of the P-M system can be obtained. Without such an interaction, no achievement of the objectives is possible.

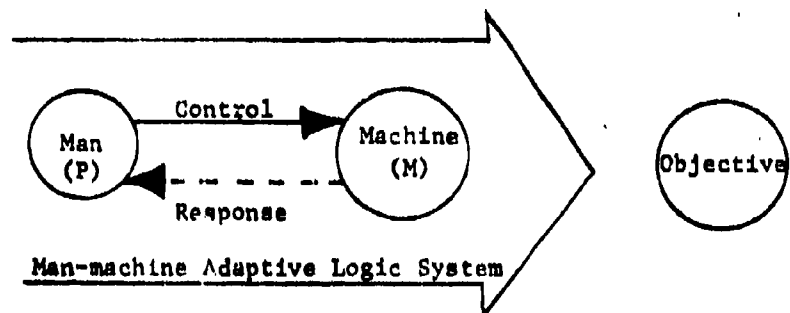


Fig. 1. A conceptual model of man-machine interaction.
(From Ting and Badre, 1976)

In a P-M system, the man's function can be classified into three categories: sensing, cognitive processing, and controlling. The machine component consists of the input, selection, and output functions. The nature of the man and machine functions are similar, but man plays an active role and the machine plays a passive one.

In a P-M interaction, the P senses the information displayed by the M. After the message is transmitted, P encodes it, interprets it, understands it, and, finally, reaches a decision. (At this level and perhaps in a separate study, it becomes necessary to identify the information processing limits and capabilities of the human and the augmentation technologies required to support and enhance them.) The P then proceeds to take an action to control the M by requiring it to perform certain functions in which he is interested. The M is designed to accept P's control via its input operations. The messages are converted to machine-understandable form in order to select an appropriate display according to a set of predetermined procedures and a chunk of pre-stored information. The selected information is then converted into a form acceptable by P, and is presented through the display system of M. The process of the interaction can be illustrated in the flow-model of Figure 2.

Success of the interaction is actually controlled by P's decision, but it is affected by M's capability in accepting the

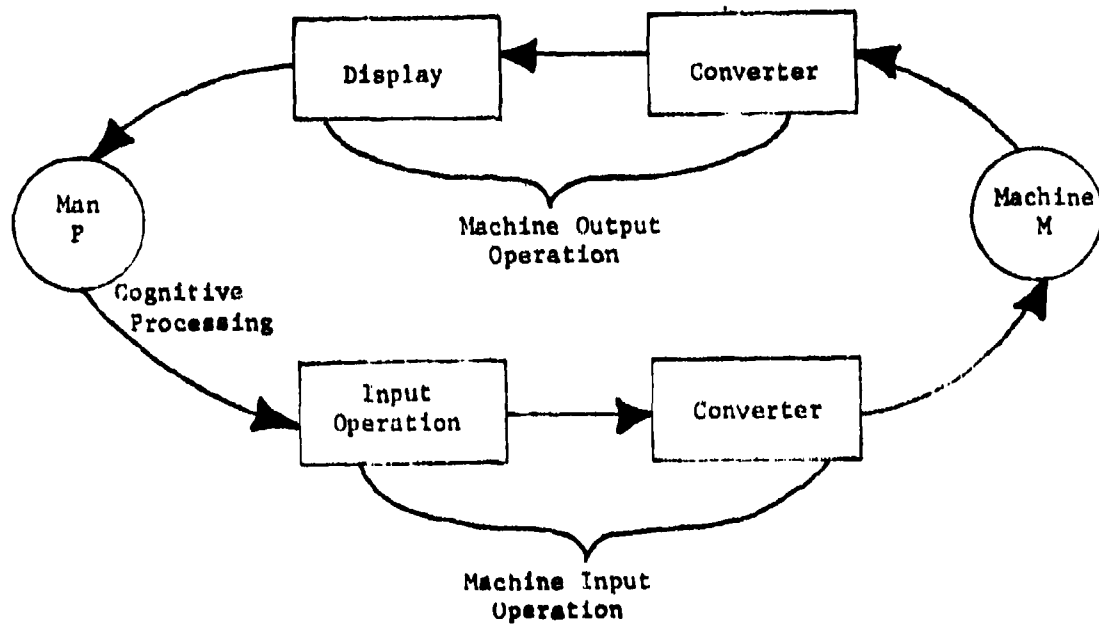


Fig. 2. A flow-model of man-machine interactive loop.
(From Ting and Badra, 1976)

commands and displaying the desired information. The P's decision may be influenced by two variables: (1) P's past experience, intelligence, or abilities, in sensing and control; and (2) the compatibility of M's input/output, I/O, operations to P's sensing and controlling abilities. The success of this compatibility is directly related to P's satisfaction with the P-M interaction. The degree of success of the P-M interaction in turn may be indicated by observing P's satisfaction with M's performance. A low quality of P-M interaction, would decrease the likelihood of a successful attainment of the desired objective. On the other hand, the better the interaction, the greater the probability for achieving the predetermined goal. A system's designer should take into account both of the above-mentioned variables to design an M such that it is co-adaptive.

Based on this initial elementary model of man-machine interaction as developed in earlier research (Badre and Ting, 1974; Ting and Badre, 1975; Ting and Badre, 1976), it is possible to develop and specify the parameters for more complex models requiring more than one P interacting with one or more M's. Such models would attempt to represent situations where the Ps have different functions that require different responses from one or more M's.

4. The Processing of Information by Humans in Interactive Computing

It is becoming increasingly clear that the effectiveness of tools intended to aid human information processing depends on the compatibility of such "artificial" aids with the needs and functionings of the human cognitive process (Gedye, 1973; Badre, 1974). By an aid we mean any tool that performs specific functions which augment the constrained capabilities present in the human cognitive structure. If by using such an aid human information processing becomes more efficient, then we call the aid "effective". An adding machine is one such tool. Another is the availability of large data banks for decision processes that require extensive aggregate analyzing.

We assume that in order to design and implement effective aids, we first must identify the user information limitations and capabilities for on-line interaction. This may be done through a formal description of a plausible human information processing model. The assumptions and processing components of the model stem largely from the findings of empirical research in the behavioral sciences. Then through model analysis we would determine the operational limits of the various processes within the system. By identifying the limits we will have coterminously defined the processing needs. Those needs would then constitute the basis for suitable aids. But because processing needs vary over different

situations, the description of the model and hence the identification of needs are situation-limited. In this regard, the interest is in the class of situations, whereby the information-processor is a decision-maker confronted with a dynamic problem situation. Problems posed to be solved with the aid of a computer in the interactive mode may be generally characterized as dynamic. They are dynamic in the sense that the problem posed by the user, e.g., a query or a request, may be modified depending on the machine's response, which itself may be a query or a response leading to a slightly different formulation of the problem. Hence, what follows is a descriptive analysis of a human information processing model that is geared to the capabilities and limitations of processing in dynamic problem situations.

4.1 Dynamic Decision Situations and Representational Shifting

The question posed here is: What are the information processing limits, underlying the development of effective aids of a decision-maker confronted with a dynamic problem situation or an ill-defined problem. This is a situation where the statement of the problem contains incomplete information. It is an "open" statement such that the necessary and sufficient information is not fully specified to the problem-solver (Raitman, 1963; Newell, 1968). More precisely an ill-defined problem-statement is one lacking in at least one of three specifications (Kochen and Badre, 1974): (1) a set of problem solutions, e.g., natural numbers =

1,2,3,...; (2) a set of solution-properties, e.g., $x: y = 2n$, n -integers; and, (3) a set of solution-methods required by the problem, e.g., arithmetical operations.

When a decision-maker, P , is faced with a decision-problem, such that at least one of the three sets above is left unspecified in the statement of the problem, then P must move to reformulate the problem-statement by specifying the missing set(s). This process of having to reformulate the problem-statement makes it necessary for P to shift his representation of the problem. Hence statement reformulation means the generating by P of a representation at s_1 that differs from P 's representation of s_0 . The states, s_0 and s_1 , are nodes in a state transition space $S = \{s_0, s_1, \dots, s_n\}$ such that s_n denotes the problem-state when P selects an admissible representation of the problem. A representation $R(t)$ at a given time t is characterized by the 4-tuple $L(t), H(t), B(t), F(t)$ such that $L(t)$ is an internal processing language specified by terminal and non-terminal vocabulary denoting constants and variables; $H(t)$ is a set of hypotheses, its members well-formed sentences, H_1, \dots, H_n and with H_1 is associated a weight $w_1(t)$ and a saliency $a_1(t)$, $i = 1, \dots, n$, where n equals the number of salient hypotheses; $B(t)$ is a data base associated with a system of interpretation and consisting of a set of elements in a universe of discourse which can be compared to observed states of the external environment; $F(t)$ is the set of rules of inference. This

property of a representation allows the transfer from one hypothesis to another.

A representation is said to lead to an effective solution if there is a finite sequence of successive hypotheses in $H(t)$, that follow from each other by rules of $F(t)$ such that the first one mentions the current state to be so, and the last one mentions the current state to be the goal state and the first few hypotheses are all in $H(t)$ leading to the last one, the consequence. In the process of achieving a well-defined problem statement, P shifts representations. A shift of representation is said to occur if $L(t_0) \neq L(t_1)$ or $H(t_0) \neq H(t_1)$ or $B(t_0) \neq B(t_1)$ or $F(t_0) \neq F(t_1)$. Shifts in $H(t)$ are characterized by changes in weight and saliency of hypotheses.

It has already been demonstrated that an information processing system that has to cope with an ill-defined problem-situation must possess the capacity to shift representations (Badre, 1974). We now ask: What constitutes a plausible model for a human information processing system that has to cope with an ill-defined problem-situation? More specifically, what sort of processing takes place when: (1) the initial statement of the problem is ill-defined; and, (2) shifting of representation occurs?

4.2 A Shifter-Based Human Information Processing Model

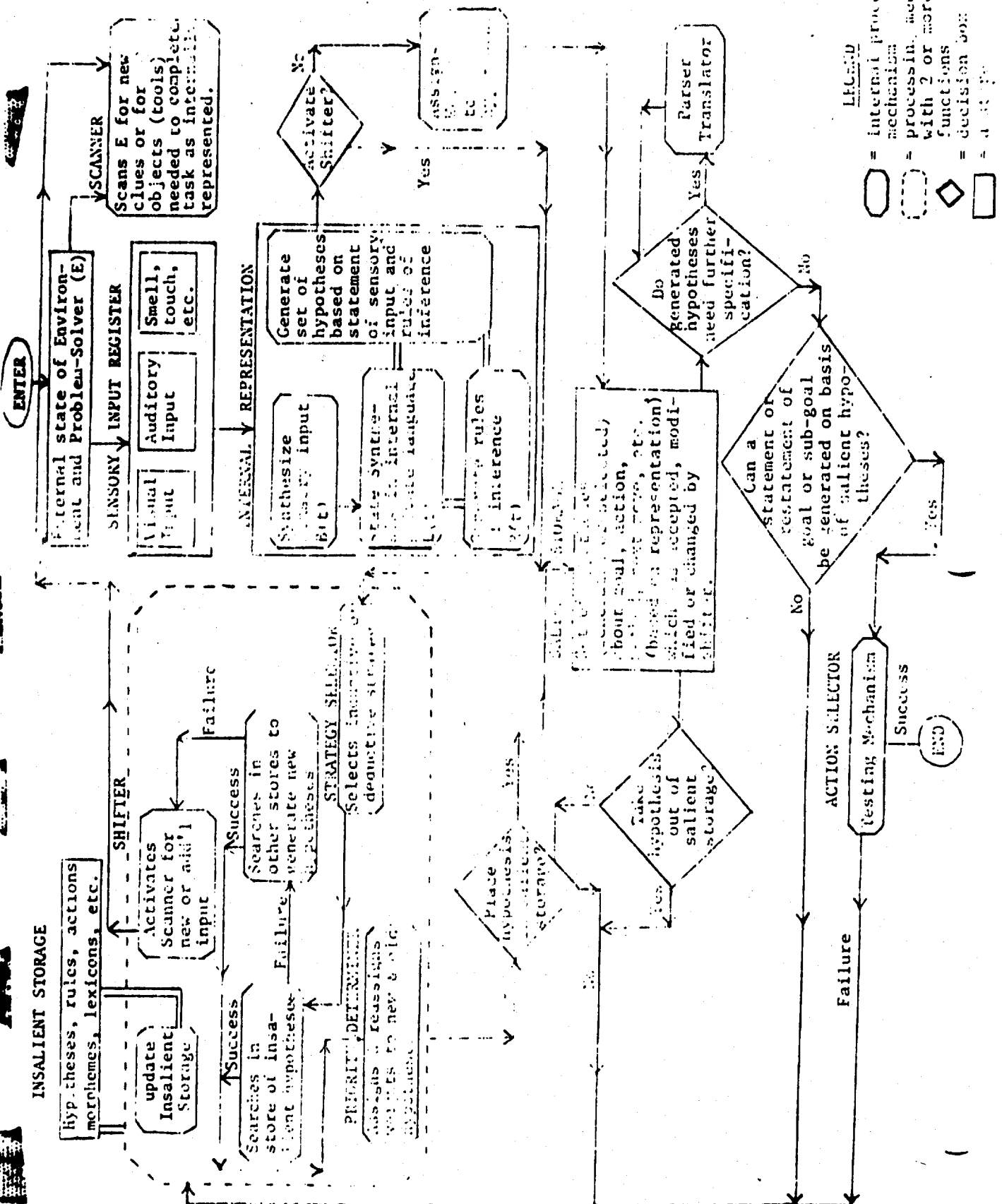
A problem-statement may be posed in one of many ways. It may be a set of instructions given as a verbal auditory statement

or visual input. For computers, it could be a program read into memory for the purpose of executing a task. Regardless of the exact mode of presentation, a translation process takes place which re-presents the problem-statement in terms of an internal language, defined earlier as $L(t)$, one of the 4-tuples that characterize an internal representation. The flow chart of Figure 3 is a representation of human information processing that is in part grounded in the results of empirical research. It attempts to explain what happens when an ill-defined by goal-oriented instruction is given.

The most important aspect which distinguishes this human information processing model from others is the emphasis placed on the centrality of the shifting mechanism, the shifter. What follows is a description of the various stages that a shifter-based information processing system might undergo. But first we begin with a brief description of the basic structures with which the shifter interacts as it functions (see figure 3).

4.2.1 The External State

This is the state of the environment, $S(t) = S(t_1), S(t_1), \dots, S(t_g)$ at any time t . The initial state, $S(t_1)$, is a description of the state of the environment and the problem-solver when coping begins. The final or goal-state, $S(t_g)$, is the state of the environment and the problem-solver when coping ends. An example of $S(t_1)$ would be, "trapped in the dark wilds and tired", or "an office room and problem for me to recognize and solve; a little bewildered".



4.2.2 Sensory Input Register

The sensory register is a mechanism by which of the millions of bits in the external environment, only a few are channeled into the cognitive system and allowed to register. Its main purpose is to act as a passive receiver and filterer of environmental sensory inputs. An example would be registering the shape, color, and texture of an object as the initial input of a problem involving such an object.

4.2.3 The Scanner

This mechanism differs from the sensory register in that it acts on the environment; the sensory register is basically a reactor to the environment. The scanner however is controlled and activated by the shifter. It always acts with an orientation, with a purpose. It scans the environment for particular kinds of objects that are designated by the shifter. An example would be the case of a lost hiker who decides to pitch a tent; he searches the environment on command from the shifter for a cord-like object in order to tie two poles.

4.2.4 The Internal Representation

This is an internal state of the problem solver that involves a synthesis of the data base, $B(t)$; a statement of synthesis in internal language, $L(t)$; a set of hypotheses, $H(t)$, generated from the statement of synthesis, utilizing a set of rules of inference,

F(t). An example would be, after registering the various features of the soma cube as input, the problem solver represents the problem: "Put together the seven dispersed parts of the soma cube."

4.2.5 Insalient and Salient Storage

The proposed information-processing system contains two primary kinds of storage or memory-banks: (1) the store of all items, information, experience, hypotheses, methods, morphemes, symbols, lexicon, data, etc., which the system at one time or another utilized and processed but are now insalient; we call this insalient storage; (2) the store of hypotheses that are immediately (within seconds) salient to the system; we call this salient storage. An example of an item in insalient storage would be what was said on line 5, page 3 of this report. An example of an item in salient storage would be what was just said.

How do the notions of salient and insalient storage relate to what has been called, in the literature, short and long term memory? One of the conclusions is that retrieval from insalient storage for the purpose of selecting and generating hypotheses is essential to coping well in dynamic problem situations. The notion of salient and insalient storage is similar to some of the accepted models for human memory (Atkinson and Shiffrin, 1968; Bower, 1972). But the model suggested here differs in at least two major ways from the models that have been advanced in the

literature. These are: (a) the function of the "attending" process; and (b) the probability assumption associated with the set of hypotheses in salient storage (STM).

The models reviewed in the recent literature (Greeno and Bjork, 1973) generally represent memory as a three-way storage (see figure 4). These consist of: (1) a sensory-register which has the main function of receiving stimuli (information) from the environment. Within a matter of milliseconds, most of this information is lost. Very little information registers or "receives attention" and is processed further into the memory system; (2) the salient information goes from the sensory register to short term storage (STM) (Broadbent, 1963). This is a buffer (Philips, Shiffrin, and Atkinson, 1967) which holds up to few chunks of information. The exact or optimal number has not been verified. The buffer is such that each new item of information that enters it, causes the oldest item in it to be lost. The processing that takes place in a buffer is similar to what we called earlier a low-saliency shift. The difference is that what is replaced in a buffer is the oldest item in it, i.e., replacement is a function of time; what is replaced in our salient storage is the item that was rejected under test, i.e., replacement is a function of weight. It is generally held that information stored in STM is either lost or processed and used. Information is lost either through decay or replacement. It is not clear however whether decay means expulsion from the

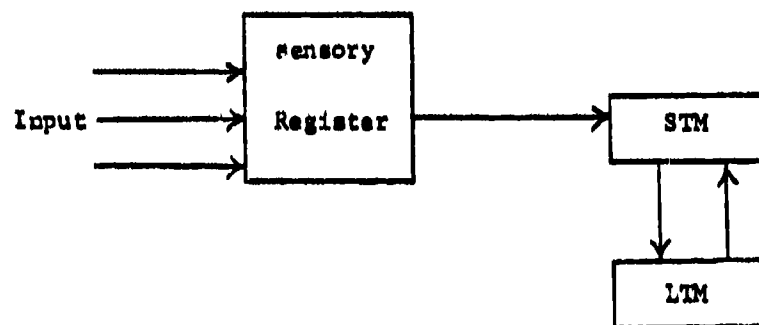


Fig. 4. A three-way-storage memory system

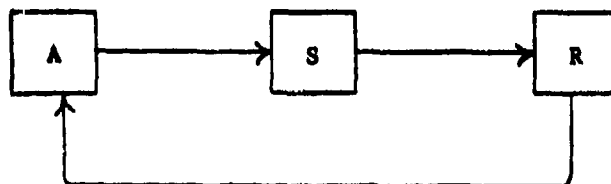
system or irretrievable storage. Information that is not lost within seconds goes on to long term memory (LTM); (3) long term memory is another term for what we called insalient storage. There is wide disagreement on what exactly constitutes the contents of LTM. Little is known or has been done on the retrieval processes from LTM. However, it is generally agreed that LTM has the capacity to store a large amount of information, most of which is difficult to retrieve. Some investigators have rejected the need and rationale for separating storage into long and short term. Yet, such separation is not without foundation. The basis for distinguishing between the two kinds of storage lies in; (a) the number of items that may be held in storage, and (b) the ease of retrieval. In our case, we justified such separation on a two-valued saliency dimension. If an item is not within immediate attention, it is in insalient storage; otherwise, it is saliently stored. The capacity-number of items, e.g., hypotheses, may be a distinguishing factor. It seems plausible to assume that insalient storage has the potential to contain many more items than does salient storage. The actual differences in amount of storage may be due to the differences in individual processing systems.

The system proposed here differs from those described in the literature in two respects: (1) what is called "attention theory" in psychology (Anderson and Bower, 1972; Kintsch, 1970;

Trabasso and Bower, 1968) deals exclusively with stimulus and stimulus-feature recognition. It assumes that the attention mechanism is activated only at the initial stages of the processing, and operates exclusively on environmental input. In our system, attention mechanisms operate at all points in the process. We have three mechanisms for attention: these are located in the sensory register, the internal representation, and the shifter. What eventually becomes salient is not due to the sensory register alone as is the case with psychological "attention theories". It is inconceivable that what we place in salient storage in order to use, e.g., test or state verbally is limited to the initial attention phase. Thus our system, unlike others, assumes an all-pervasive (internal) attention process.

(2) The second essential difference between the model we propose and those reviewed in the literature (Greeno and Bjork, 1973) has to do with the assumption of an equi-probable space of hypotheses-selection (Restle, 1962; Wickens and Millward, 1971). This assumption manifests itself most clearly in the work done under the concept-identification (CI) paradigm. The original models proposed by Restle (1962) assumed that sampling of hypotheses from a "pool of hypotheses" is independent and with replacement. A subject selects randomly an hypothesis in order to test it. If it is rejected, he throws it

back into the pool with an equal chance of its being reselected. This simple model, which assumes a memory-free process, was further modified by Trabasso and Bower (1968). By extending the notion of "local consistency", they suggested that rejected hypotheses will remain in memory for a short period of time before being placed back in the equi-probable pool. They also modified the model to allow for the consideration of more than one hypotheses at a time. Wickens and Millward (1971) incorporated these two modifications into their "attribute-elimination model". The assumptions of their model are represented in the following flow-diagram:



A = the set of all possible hypotheses, $\{h_1, h_2, \dots, h_1, \dots\}$,
 where h_1 is any hypothesis in A.

S = the set of hypotheses selected from A to be tested, with
 size, s.

R = hypotheses rejected, but remembered as such, with size, r.

The subject presumably samples randomly from A and places few hypotheses in S for the purpose of testing. If these are rejected, they go to R, where they remain in a buffered situation until they go back to A. The assumption of equi-probability still holds. Hypotheses in A have equal chance of being selected into S and tested. This may be expressed as $P(h_i \text{ selected} | h_i \in A) = \text{the ratio, } \frac{S}{A}$.

The assumption of equi-probability, which seems to pervade all CI models, does not hold when one holds to a two-stage process: the selection and the testing of hypotheses. It is therefore reasonable to assume that hypothesis selection or generation is not equally probable before placement in salient storage, because it is determined by the shifter's actions, which in turn are determined by the shifter's history of training. The elimination of the equi-probable candidacy for salient storage affected by the use of the shifter, is what differentiates the assumptions of mathematical models based on the system we are proposing from the assumptions generated under the CI paradigm. The selection-generation of hypotheses process is not equi-probable. However, it is possible that once hypotheses are in salient storage, equi-probability holds; all salient hypotheses have an equal chance of being assigned the highest weight. In our terminology, a high-saliency shift, requiring only change in weights, will occur with equal probability over all salient hypotheses. This means that when we have a high

saliency task, shifting occurs with equal probability.

4.2.6 The Shifter

After the problem is internally represented, one of two things may happen: (1) the generated hypotheses could pass to salient storage with no operation on them by the shifter. In this case the hypotheses are accepted by the system exactly as they are with no alterations, and allowed to pass into salient storage in order to be tested; (2) a more active utilization of the shifter may be characterized at two levels: (a) one way is to parse the representation in terms of the inquiring-strategy to be used. This can be effected by activating the strategy selector. The result would be to eliminate from candidacy some of the hypotheses for salient storage. If let us say the selector picks an inductive strategy, one geared to high specificity, this would eliminate most of the generic hypotheses which otherwise would have been equiprobable candidates for salient storage. Once the selector chooses a particular strategy, it would block the usage of any noun-phrase or qualifier which is not in correspondence with selected strategy. It would do this by using a scheme similar to that developed and used for coding subjects' verbal protocols (Kochan and Badre, 1974). (b) Another way of activating the shifter is to utilize one or more of its processes of retrieval from insalient storage. When a representation is selected, it may be important to activate

retrieval functions which look for hypotheses, information, experiences, etc., which may be associated with the incoming representation. Then it would generate or select new testable hypotheses as candidates for salient storage. The shifter can also activate the scanner if representation is not acceptable, or, if retrieval from insalient storage is unfruitful. The end-result of the shifter's activities is to accept, modify, or replace the internal representation. Once it decides on an acceptable representation, it places a handful of associated hypotheses in salient storage.

What are the working priorities of the shifter and how does it function? The shifter makes it possible for the system to "entertain" and "disentertain" representations and associated hypotheses in order to test them. A set of salient hypotheses is put through the testing process. A statement of goal or hypothesis about goal or sub-goal is formulated and tested. If it cannot be formulated or is rejected or is partially accepted, then from one to all of the salient hypotheses will go back to be "reentertained" by the shifter. The following conditions hold:

- (1) If a goal-statement hypothesis is totally rejected under the test, then all of the salient hypotheses go back to shifter for either (a) a replacement of representation (a between-representation shift), or (b) a "complete" within-representation shift (complete replacement of group of salient hypotheses with

another group, associated with the same representation).

(2) If goal-statement hypothesis is partially accepted, i.e., acceptance of a sub-goal or an auxiliary goal is affected, then one or more, but not all of the salient hypotheses (the hypotheses that have been rejected or received a different priority under test) go back to shifter to be reentertained. This is done by either (a) changing their weights (high-saliency shifting), or (b) replacement with new hypotheses from insalient storage (low-saliency shifting).

If these are the conditions under which shifter operates on a representation or an hypothesis, then what operations take place in shifter: (a) when a complete within-representation low saliency shift takes place; (b) when a shift of representation is performed; (c) when a low-saliency shift is performed; (d) when a high-saliency shift is performed?

(a) The following steps are involved in a complete low-saliency shift:

STEP 1 All of the hypotheses are retrieved from salient storage.

STEP 2 They are disentertained (placed in insalient storage).

STEP 3 Next, the shifter calls on the store of insalient hypotheses and looks for hypotheses which may be associated with the held representation.

STEP 4 If it succeeds, it runs the selected hypotheses through the strategy selector where an inquiry-strategy is chosen.

STEP 5 The strategy selector eliminates (filters out) those hypotheses and words which do not accomodate the chosen strategy. It acts as an inquiry-strategy filter. The inquiring strategy and the frequency of shift from one strategy to the next is predetermined by the history of the system. (In a human, whether he uses an inductive strategy or a deductive one is determined to a great extent by his past learning and experiences in inquiry.) In fact, the selector is a program that stimulates such history and which thus determines when to shift from one strategy to another.

STEP 6 From the strategy selector, the hypotheses go to the priority determinant, where priority weights are assigned.

STEP 7 If the shifter fails in selecting relevant hypotheses from insalient storage, then it calls on the store of knowledge data, the store of lexicon, the store of methods, the store of morphemes, and the store of rules.

STEP 8 By using two or more items in these stores, it attempts, through the process of concatenation, to generate new hypotheses that can be associated with held representation.

STEP 9 Then it goes through steps 4, 5, and 6.

STEP 10 If shifter fails in generating new hypotheses from insalient storage as it failed in selecting insalient ones, then it disentertains the representation it is holding.

STEP 11 It does that by (a) placing representation in insalient storage, and (b) activating scanner in order to generate a new representation.

STEP 12 When the new representation is generated, with it comes a set of new hypotheses which are automatically placed in salient storage.

(b) When a shift of representation occurs, steps a-11 and a-12 are implemented.

(c) When a low-saliency shift is performed, that means that one or more but not all of the salient hypotheses are disentertained; they are replaced by hypotheses from insalient storage through steps a-3, a-4, a-5, and a-6 or a-7, a-8, and a-9. A lock-in effect occurs when neither of those two sequences of steps results in retrieval of hypotheses from insalient storage. In such a case, the scanner is activated for the purpose of bringing to attention clues that may help retrieval (whether by selection or generation) from insalient storage.

(d) When a high-saliency shift is performed, this means that the shifter recalls one or more of the salient hypotheses for the sole purpose of putting them through the priority determiner which reassigns their weights.

4.2.7 Parser-Translator Synthesizer

From salient storage, the hypothesis goes to the test. If the hypothesis is comprehensible to the system then it goes to the

statement-of-goal-loop to be tested. If on the other hand, it is incomprehensible, or needs further specification, as in "set up a camp", then it is put through the parsing, translating, synthesizing process. First the parser takes the hypothesis-sentence and separates it into elementary sentential vocabulary such as quantifiers and predicates. Then the translator provides each element in the vocabulary an interpretation. The synthesizer concatenates the new interpreted vocabulary elements into a sentential structure acceptable to the system. This process goes on repeatedly until no further specification is needed. The problem-solver could resort to external dictionaries or resources, if he is unable to decode and specify a given sentence. If he fails to translate, then he either gives up or goes back to shifter for change of hypotheses or representation.

4.2.6 The Statement-of-Goal-Loop and the Testing Mechanism

Once it is decided that hypotheses-sentences need no further specification, the process to generate and test a statement of immediate goal based on salient hypotheses begins. The problem-solver might say, "my goal is to pitch this tent". The salient hypothesis that gives rise to this goal is: "If I use this old piece of canvas, I will be able to have a tent-like shelter". If a statement of goal cannot be generated on the basis of salient hypotheses, then hypotheses go back to shifter, where they or the

representation will be changed for the purpose of appropriating a goal-statement. Once a statement of goal is formulated, it goes through the process for the purpose of execution. If it cannot be executed, then the execution of a sub-goal is considered. This takes the system back to the reformulation of a sub-goal statement. Problem-solvers who do not utilize the shifter quite often and in an active way, may end up in an extensive looping process with no success until they decide to give up. It is possible that this loop is the cause of redundancy and repetitiveness in problem-coping. Utilizing the shifter is the only way the problem-solver can break the statement-of-goal-test-loop. This all-pervasive reliance on shifting throughout the process makes the shifting mechanism the most central aspect of this system.

4.3 Analysis of a Shifter-Based System

It can be seen from the above description of the shifter's functions, that without its activation, an information processing system would be at best a passive transmitter of and reactor to environmental inputs. Without the shifter, problem-solving in ill-defined problem-environments is not likely to succeed or be efficient. Most of the tasks we encounter as information-processors and problem-solvers are ill-structured. In these cases, if we can predict average rate of shifter's activation for a set of conditions and a given population of decision-makers, then we can develop aids to augment and enhance shifter's activity under specified conditions.

But most of the tasks we encounter are not of the high-saliency type and would require the active use of the shifter. In these cases equi-probability over hypothesis testing will not hold, as hypothesis testing will be a function of both what is generated into salient storage as well as what is assigned the highest weight.

Let ψ = rate of shifter's activation, with values ranging in the interval, $[0,1]$.

β = proportion of generic to specific questions.

$H = \{h_1, h_2, \dots\}$, the set of all possible hypotheses.

$H_{1s} \subset H = \{h_1, h_2, \dots, h_m\}$, the set of all insalient and generatable hypotheses, with m = the size of H_{1s} .

$H_{hs} \subset H = \{h_1, h_2, \dots, h_n\}$, the set of all salient hypotheses, with n = the size of H_{hs} .

On the assumption that $h_1 \in H_{1s}$ at time t becomes $h_1 \in H_{hs}$ at t_1 , let:

$$a = \text{Prob}(h \in H_{hs}, \text{ at } (t + dt) | h \in H_{1s} \text{ at } t)$$

$$1 - a = \text{Prob}(h \in H_{1s}, \text{ at } (t + dt) | h \in H_{1s} \text{ at } t)$$

$$b = \text{Prob}(h \in H_{1s}, \text{ at } (t + dt) | h \in H_{hs} \text{ at } t)$$

$$1 - b = \text{Prob}(h \in H_{hs}, \text{ at } (t + dt) | h \in H_{hs} \text{ at } t)$$

We can thus generate the probability matrix

$$\begin{array}{cc}
 & \begin{array}{c} t + dt \\ \hline \end{array} \\
 & \begin{array}{cc} H_{1s} & H_{hs} \end{array} \\
 \begin{array}{c} H_{1s} \\ \\ H_{hs} \end{array} & \begin{pmatrix} 1 - a & a \\ b & 1 - b \end{pmatrix}
 \end{array}$$

$$P(t) = P(h \in H_{hs}) \text{ in } (t, t + dt)$$

$$P(t + dt) = P(t)(1 - b) + (1 - P(t))a$$

The experimental data supports the assumption of plurality that when the proportion of generic to specific questions $\geq .35$ and $\leq .65$, the problem solver performs better in time to shift than if the proportion were otherwise. Also performance is dependent on the time to shift. Time to shift is determined by the rate at which the shifter is activated. If ψ increases from 0 to 1, time to shift will decrease. This assumption can be justified as follows:

Let c = probability of shifting to a useful hypothesis any time shifting occurs.

T = number of minutes for the correct shift to take place for the first time.

Then, given coping performance = time to shift, and by the assumption that the event of the correct shift occurring in any one-minute

interval is statistically independent of the event of the correct shift occurring in any other one-minute interval

$$P(T = g) = (1 - c)^g c = ce^{-cg}$$

The mean number of minutes to the first correct shift = $\frac{1}{c}$.

g is proportional $\frac{1}{c}$

Given these assumptions, the following holds true:

$$P(h_1 \text{ generated } \psi, \beta = x) \begin{cases} \frac{\psi}{x} & \text{if } 1/3 \leq \beta \leq 2/3 \\ \psi x & \text{if } \beta < 1/3 \\ \psi(1-x) & \text{if } \beta > 2/3 \end{cases}$$

Those values of β are supported by our preliminary results.

Let: C_1 denote $1/3 \leq \beta \leq 2/3$

C_2 denote $\beta < 1/3$

C_3 denote $\beta > 2/3$

It can readily be seen that:

$$P(h_1 \text{ generated } | C_1) = \int_{2/3}^{1/3} \frac{\psi}{x} f(x) dx$$

$$P(h_1 \text{ generated } | C_2) = \int_0^{1/3} \psi x f(x) dx$$

$$P(h_1 \text{ generated } | C_3) = \int_{2/3}^1 \psi(1-x) f(x) dx$$

where $f(x)$ is the probability density function of β .

$$P(\psi > 0 | \text{Low saliency problem}) = T = .5$$

$$P(\psi = 0 | \text{Low saliency problem}) = LT = .5$$

What is the probability that $h_1 \in H$ is tested?

Let $A = \{a_1, a_2, \dots, a_k\}$ = the set of hypotheses in salient storage, with k = the number of salient hypotheses, then: given A , by the assumption of equi-probability:

$$P(a_1 \text{ tested} | a_1 \in A) = \frac{1}{k}$$

$$P(h_1 \in A | h_1 \text{ generated}) = 1$$

The probability of testing, given a low saliency task is readily derived as:

$$P(h_1 \text{ is tested}) = P(h_1 \text{ is tested} | h_1 \text{ is generated}) P(h_1 \text{ is generated})$$

$$P(h_1 \text{ is generated})$$

$$= P(h_1 \text{ is generated, shifter is active})$$

$$= P(h_1 \text{ is generated, shifter is active}) P(\text{shifter is active})$$

$$\times P(h_1 \text{ is tested})$$

$$\text{Thus: } P(h_1) = P(h_1, C_1) + P(h_1, C_2) + P(h_1, C_3)$$

$$P(h_1, C_1) = P(h_1 | C_1) P(C_1)$$

$$P(h_1, C_2) = P(h_1 | C_2) P(C_2)$$

$$P(h_1, C_3) = P(h_1 | C_3) P(C_3)$$

$$P(h_1) = P(h_1 | C_1) P(C_1) + P(h_1 | C_2) P(C_2) + P(h_1 | C_3) P(C_3).$$

To obtain the probability that β assumes a value between any numbers, a and b , we must integrate using the probability density $f(x)$ from a to b for any given value $f(x)$. We assume that β is uniformly distributed:

$$f(x) = \begin{cases} 1 & \text{for } 0 \leq x \leq 1 \\ 0 & \text{otherwise.} \end{cases}$$

$$\begin{aligned} \text{Thus } p(h_1 \text{ is tested}) &= \int_a^b P(h_1 | \beta = x) f(x) dx \\ &= \frac{T}{k} \left(\int_{1/3}^{2/3} \frac{\psi}{x} f(x) dx + \int_0^{1/3} \psi x f(x) dx + \int_{2/3}^1 \psi (1-x) f(x) dx \right) \\ &= \frac{T\psi}{k} \left[\frac{1}{3} \frac{x^2}{2} \Big|_0^{1/3} + \frac{1}{3} \ln x \Big|_{1/3}^{2/3} + \frac{1}{3} \frac{(1-x)^2}{2} \Big|_{2/3}^1 \right] \end{aligned}$$

Based on the experimental literature, (Wickens and Milward, 1971; Trabasso and Bower, 1968), k may be assumed to be about three hypotheses. Thus $\frac{1}{k} = \frac{1}{3}$. β can be determined from the subject's protocols through the process of question content analysis. With k and β readily available, ψ , the rate of shifter activation, can be easily derived. We can use this model to predict shifting performance in ill-defined problem-situations. If the predictions based on the model, fit the data, then the assumptions associated with the model, concerning internal cognitive processes, will be considered plausible.

5. Selected Human Factors in Interactive Information Processing

One of the most crucial problems that is yet to be properly posed and solved in designing efficient computer based man-machine logic systems has to do with identifying the most effective representations for information flow between the man and machine components. Given that the machine and the human are interacting at a cognitive processing level, it becomes necessary to identify the most effective language media as well as sequencing of flow and feedback of information to and from both the human and machine components. The type of sequencing and the rates of flow and feedback will necessarily vary as a function of the roles of both the human and computer components. For example, if we have a system where the machine is the information analyst and the human component is composed of two distinct individuals, an information gatherer and a decision maker, then the information feedback requirements of the two individuals are substantially different and would give rise to different responses from the machine. Furthermore, in the case of a multi-purpose system, it is not at all clear what is optimal interactive feedback. When given a system involving at least one information gatherer, one decision-maker, and an information analyst, several feedback and human factors related questions may be legitimately posed: should the individuals in the human-component be able to interact with each other? Should the interactive feedback function be implemented between the machine and each individual?

Should we implement a one-way flow of information? How would networking at different levels of feedback from the non-dynamic one-way flow of control type to the interactive looping type affect the human's ability to make decisions, solve problems, learn, and process information? What communication language and graphic facilities should be used to enhance the system's effectiveness? How would different input and output devices affect the usability of the system? How should the data be entered and retrieved in a user-compatible way? How can we design the internal structure of the data base such that its management will be facilitated? These are questions concerned with interactive human factors in computing that will have to be posed at an empirical level by those interested in enhancing the usability of computers by humans in situations requiring information gathering and analysis as well as decision-making.

The purpose of this section is to delineate some of the important design aspects of interactive systems as they may be viewed from a human factors perspective. In the past fifteen years the main overall "user" emphasis of the designers of management information systems has been on determining the information needs of the users of such systems. The predominant questions were: What information does the user need? In what order and format does he use his information? What should constitute the contents of the data base? Then once these questions are more

or less satisfactorily answered, through various data collection techniques such as structured interviews and user questionnaires, the attempt was to build a data base into a system that meets the constraints of the present technology. While the attempt was to meet the information needs of the user, hardly any effort was spent on determining and attempting to meet the information processing capabilities and limitations of the different types of human users. For example, "how" the information is organized, processed, and used in the human memory may have an impact on the type of structure to be selected for the data base. Likewise, how the human assimilates either graphic or textual information may impact how such information should be represented and organized on displays which in turn may impact the choice of displays. Also, a determination of how to effectively display information would lead to a selection of compatible methods for querying and searching the data base. The point of all those examples is that a determination, no matter how inconclusive, of the human information processing capabilities and limitations will go a long way towards making the design of such systems more user compatible. The plan here is to select two or three components of an interactive system and discuss the relationships between human information processing variables and the design of the selected components. More specifically, the emphasis will be on two aspects of interactive computing: (a) the effective

display of information and user-compatible output; and (b) human memory organization as it relates to data base management.

5.1 Information Display in Interactive Computing

Research regarding the effects of information display on its assimilation by the human user has been conducted extensively (Jervis, 1970; Antonelli, 1970; Vartabedian, 1970, 1971; Smith and Goodwin, 1972; Reynold, White, and Hilgendorf, 1972; Baron and Duffy, 1974; Cahill and Cortes, 1976; Stewart, 1976; Helper, 1976). Most of this research concentrated on the psychophysical aspect of the displaying and processing of information. The user's response to displayed information may be affected by many factors. Based on various research results, it is generally agreed that the display would have to exhibit the proper physical characteristics. It should be free of flicker. The characters should be sufficiently large such that they can be read easily. The displayed information should have adequate contrast and protection from glare (Martin, 1973). In addition, the symbology used should not be ambiguously similar thus leading to interference effects.

Character type can affect user response to the display. A study by Vartabedian (1971) compared stroke characters with 7x9 dot matrix characters. In a scanning task, users took 9.5% more time on the stroke display and made a surprising 73% more

errors. Vartabedian also took a preference survey and found that the users subjectively preferred the dot matrix characters. Vartabedian also compared user response between upper case and lower case characters. Users were 13% faster on upper case and made fewer errors. These studies were done with CRT displays and do not necessarily apply to other types of displays.

Studies that compare the effects of intermittent and continuous display indicate that "one long exposure yields better results than a combination of shorter exposures" (Heppler, 1976). The blinking of displays leads to an increase of 10% in reading time (Smith and Goodwin, 1972). Studies on noise in display systems have been inconclusive (Antonelli, 1970). In cursor studies, it was shown that the type of cursor affects user response. Vartabedian (1970) compared box, underline, cross, and diamond shape cursors in terms of the effects of blinking and wiggling the cursor. He compared blink rates of 0, 2, 3, 5, and 6 H_2 . The best cursor was a box blinking at 3 H_2 .

Some studies have looked at the modes of auditory and visual presentation and various combinations thereof. A test of short term memory recall found no difference except that performance deteriorated if modes were switched during presentation (Fell and Laughery, 1969). Another experiment using a teletype rather than a CRT presented information and instruction in various

modes (Hammerton, 1975). The best combination results were to present information were to present information visually while giving instruction aurally. The next best was to make both presentations visually.

Color is another aspect of visual factors in displays. Human eyes see mid-range wavelengths such as yellow and green better than those toward the ends of the spectrum such as blue or red. Holding the dominant wavelength of the characters close to that of the background lessens chromatic aberration (Gould, 1968). Cahill and Carter (1976) examined the effect of color on the mean search time of a display for a three digit number. They found the number of colors used to range from three to seven. Speed of response to signal lights varies with color. Research findings indicate that the fastest is red, slowing down through green, yellow, and white (Reynold, White, and Hilgendorf, 1972).

Response time is an important psychological factor in interface design. In conversation humans expect a response in about two seconds. When browsing through material or using a lightpen, humans prefer a response time of a second or less. If the display is delayed, an interim response should be given. It is psychologically desirable to have a consistent response time. Users like slightly longer consistent times more than wide fluctuations (Martin, 1973).

Research on information display has been much less extensive for cognitive processing effects than for psychophysical ones. Recent findings (Badre, 1978) have suggested that users of different levels of experience and expertise tend to organize and represent the same information in differently specialized ways. This would lead to the conjecture that displayed information should be organized for presentation as a function of the user's level of experience. In a related area, the last few years have seen an increase in research on formatting. The basic kinds of formats are the positional and the keyword. In the positional format, the type of information depends on its position whether relative or absolute. These formats have higher error rates. In the keyword format, the type is directly indicated (Miller and Thomas, 1977).

The components of good formatting are logical sequencing, spaciousness, relevance, consistency, grouping, and simplicity. In logical sequencing, the information is presented in the order expected by the user. A good example can be illustrated in the statement "Do A then B" as opposed to the statement "Before B do A". The first statement maintains temporal sequence. Spaciousness helps to delineate grouping, to maintain structure, and to avoid information overload. One should limit each display to one main idea. Using a similar format on each of the displays is also helpful to the user (Stewart, 1976).

5.2 Data Base Management and Human Memory Organization

The need for better understanding of MIS (Management Information Systems) environment has been recognized. Systems which are used, operated, and maintained by humans should be designed with some consideration of the human factors that will influence the effectiveness of those systems. Among the major current approaches to the design of data base systems, the two that are most widely used are the hierarchical and relational ones.

The hierarchical structure is one in which there is an inferior-superior relationship. In a strict hierarchical system or tree structure a record may have any number of subordinate (lower level) record types, and multiple occurrences of each type may appear. However, a given record can be accessed only from one higher level record. Thus, if we have retrieved a record at a given level in a branch of the tree structure, we cannot retrieve a record in another branch directly. A second limitation is that relationships cannot be maintained with records in other trees.

In the relational approach there exists an interface at which the totality of formatted data in a data base can be viewed as a finite collection of non-hierarchic relations of assorted degrees defined on a given collection of domains.

In order to study the effectiveness of data management systems it is necessary to investigate the schemes for information storage in humans. In many cases views regarding the logical organization of data in a human's long term memory are of value in designing data base systems since they provide an insight into the way in which people will use information systems to help in solving problems. The question that is raised here is: In what aspects is human memory organization relational and in what sense is it hierarchical?

Currently there are three major theoretical positions on how information may be stored in semantic memory. These are: network, set-theoretic, and semantic distance theories. Network models assume words or their counterparts exist as nodes which are connected by labeled relations. The nodes form a hierarchical structure such that, for example, BIRD might be connected to the subordinate node ROBIN, to the superordinate node ANIMAL, and to the property nodes such as CAN FLY, HAS FEATHERS, etc. (Collins and Quillian, 1970). In set-theoretic models, concepts such as ROBIN, BIRD, and ANIMAL are represented by sets of elements where the elements may be subsets, supersets, attributes, or exemplars (Meyer, 1970). The simplest one-stage version of the theory assumes that a list of exemplars is stored with each category. If one asks whether a robin is a bird, the category

of BIRD is searched until the instance of robin is found.

Semantic distance models state that each concept has an internal structure, rather than being nodes in a network of related nodes, or homogeneous sets of instances. Rosch (1973) has discussed how sets of focal instances connected by a distance function could define how we use categories which may not correspond to a logical or formal structure. Of course any model of semantic memory must have some means of verifying logical relations, but there are now indications that such verification is not be a direct reading of the memory structure as would be accomplished by checking internode relations or category overlap (Rips, Shoben, and Smith, 1973). In any case, semantic memory models tend to rely on one of two types of structures, associative or hierarchical. The two structures seem to correspond well to the two indicated approaches of data base design.

5.2.1 Associative Structure

In recent years the question of what constitutes an association has received considerable attention. Tulving (1968) pointed out that the term association, used descriptively, merely means that one event follows another with some regularity. Postman (1968), in an effort to categorize the ways in which the term association is used pointed out six uses of the expression. These included

association as a descriptive term and as a statement of pre-existent verbal hierarchies. Finally, Asch (1969) emphasized the importance of conceiving of an association in terms of the relation of two events A and B.

Asch suggests that the problem of associations is part of the general psychology of relations and that the study of associations is in a large part the study of the properties and affects of experienced relations. In every day experience one observes that "this object stands upon that", that "it is larger" or "more tilted" than another. It was the premise of classical psychology that relations are not primary psychological facts. This premise was strong enough to blot out the evidence of every day experience. Relations were then replaced by associations and associations were made to do the work of relations. This starting point excluded what Asch considers a particularly basic range of facts concerning interdependence. A relation makes its terms interdependent. The defining property of a relation refers simultaneously to more than one term. A relation cannot be resolved into a fact about one term and a fact about another term.

If relations are crucial conditions of interdependence among psychological events, it is natural to suppose that they must control learning and memory. There are many conditions of perceptual organization which determine how easily two features

or elements of a visual field cohere and become associated. Some of these relations have been detailed by Asch, Ceraso, and Heimer (1960).

Rumelhart, Lindsay, and Norman suggest a model for the structure of long term memory in which the basic element is a set of nodes interconnected by a relation. Nodes represent any cluster of information in memory. A relation is an association among sets of nodes having the properties that it is labeled and directed. That is, relations interconnecting nodes have distinctive meanings, depending on the direction in which the relation is traversed (i.e., using the relation in the direction opposite to its label is equivalent to using the inverse of larger than). Every definable piece of information in memory is encoded in the format of a node and its relations. A node may represent a concept, event, or episode and may have any number of relations attached to it. The model they have defined is an organized collection of pathways specifying possible routes through memory. Retrieving information from such a memory is done by starting off at a given node and optionally going down any one of a number of labeled pathways. An associative model in the Norman, Rumelhart, and Lindsay sense seems to be akin to the relational approach of data base management.

5.2.2 Hierarchical Structure

Mandler has theorized that the hierarchical organization of words accounts for verbal learning in free recall. According to Miller's (1956) findings, the development of such structures in memory should constitute a sequence of recodings proceeding from small units or chunks of information to larger ones. However, Mandler has extended Miller's hypothesis postulating that verbal units or chunks are recoded into a hierarchy of "superchunks" or a set of nested categories. Consider the process in learning the names and descriptions of sixteen objects that can be successively halved into a hierarchy of subcategories or chunks according to their location, shape, material, and color. In this case, since the color dimension contains almost no information and cannot be completely subcategorized, it is predicted that the structure would initially develop at the lowest level. In order for this process to occur, it is necessary that two preconditions be fulfilled: (a) the hierarchical nature of the categories must be perceived; and, (b) the interrelations between these categories must be established. Recoding is a two stage process - a horizontal chunking or clustering within categories as specified by Miller, followed by a vertical or hierarchical chunking between successive categories as postulated by Mandler.

It was demonstrated in experiments by Bower, Clark, Leasgold, and Winzens (1969) that recall of a large list was greatly

facilitated if the experimenter preorganized it for the subject in terms of conceptual hierarchies. That is, it was shown that a subject could efficiently use a conceptual hierarchy as a retrieval plan, beginning his recall at the top node and unpacking it recursively from the top down. Other subjects, presented with the same words, but scrambled in random order, appeared not to recognize the hierarchical organization imminent in the material, not use it during recall.

Wortman and Greenberg (1971) suggest that information in long term memory will gradually be organized into hierarchical structures composed of chunks or nested categories. In particular, this is viewed as a three stage process proceeding from the initial perception of the category hierarchy, to the chunking of the lowest or bottom category within the hierarchy, and ending with the formation of links to the next level up in the hierarchy. These two processes continue until the organizational structure is complete. Their study showed that subjects given multi-trial free recall of previously learned information containing an organizational hierarchy specified by the experiment will gradually adopt this structure. The development of this structure was shown to be both facilitated and accelerated by a problem solving task stressing categorical relationships.

We have seen here that both hierarchical and relational data base systems are valid representations of information in the sense that they are organized in such a way as to facilitate problem solving in humans. To determine whether one system is better than the other for specific situations would require finding an answer to the question of whether people think and solve problems in terms of hierarchies or relations for the given cases or classes of situations.

In order to decide which approach to data organization is most suitable for a specific application one must look more closely at how the system is to be used. There are probably individual differences in the way in which information is organized and retrieved in long term memory. Thus it is likely that, depending upon the past experience of an individual in solving a problem, his representation of the data may be either hierarchical or relational. With this in mind, it is usually advised to choose the more flexible system. For example with the relational approach, it is possible to use some domains of the relations for internal system ordering in order to simulate hierarchical systems. Simulation in the opposite direction is not always feasible.

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